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814-863-6272 FAX 814-865-7389

Propulsion Engineering Research Center

106 Research Building E — Bigler Road
The Pennsylvania State University
University Park, PA 16802

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April 8, 1992

Dr. Edwin P. Rood
Fluid Dynamics Program (Code 1132F)
Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217

Subject: Progress Report on Contract #N00014-91-J-4058
"Computational Modeling of Marine Propulsors"
For Period of January 1, 1992 to March 31, 1992

Dear Dr. Rood:

This letter represents our third quarterly progress report on the subject contract for the indicated period. In addition to planned objectives stated in our last quarterly report, namely, continued efforts on the 3-D parametric Navier-Stokes study of the curved blade passage problem and further validation of our 3-D panel code for marine propellers with unsteady non-uniform inflow, our focus during this period included extensions of our Navier-Stokes code to axisymmetrical flow with swirl to study the inflow velocity profile for rotor-stator blade design and to a time-accurate Navier-Stokes solver for 2-D unsteady flow. We have also initiated a numerical analysis of acoustic noise produced by 2-D blade-vortex interaction. A brief summary of the progress in these areas follows.

<u>2-D TIME-ACCURATE NAVIER-STOKES SOLVER</u>. A 2-D time-accurate N-S solver was developed using artificial compressibility, dual time-stepping and dynamic gridding to accommodate the change of the computational domain with time. Demonstrative calculations for a pulsating pipe were conducted and compared with available perturbation solutions. The configuration of the pipe and the pressure distributions on the wall are presented in Figs. 1a and 1b.

<u>2-D ACOUSTIC NOISE PROBLEM</u>. Based on our 2-D unsteady panel code, an acoustics analysis of a blade-vortex interaction flow problem (see Fig. 2) was initiated using an asymptotic expansion technique and small perturbation formulation. In this example problem, a vortex is released upstream and its position is tracked as it is convected past an airfoil. During this time, the flowfield is calculated at each time step and along with tracking the new locations of the initial

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Dr. Edwin Rood ONR/Code 1132
Alington, VA 22217-5000

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vortex, the wake vortices shed from the blade trailing edge are also obtained. This will allow us to include the effects of the contribution to the acoustic field from the change of the vortex distribution on the blade surface as well as that due to the relocation of the upstream vortices, both of which are caused by the blade-vortex interaction when the blade passes by the vortices. Previous calculations of this problem have ignored the induced vortex effect. Work in this area is progressing well and will be continued in the next reporting period.

AXISYMMETRICAL FLOW WITH SWIRL. From experimental measurements it was found that the inflow velocity profile for fan blade design considered earlier is not uniform in the radial direction. By omitting this radial variation, the total flow volume can be overestimated by as much as 15%. It was further confirmed through numerical analysis that this radial variation of the inflow velocity is not caused by viscous wall effect either on the hub or on the casing. Thus, it was highly possible that the non-uniform distribution of the inflow velocity is caused by centrifugal force due to swirl. A N-S solver for axisymmetrical flow with swirl was developed and code validation for simple geometry was completed. Computations for realistic geometries (see Fig. 3) are currently in progress and will continue during the coming contract period.

3-D PARAMETRIC STUDY OF NAVIER-STOKES FLOW. As used in previous studies by many other people, a curved rectangular duct was chosen as representative of the secondary flows in turbomachinery. A parametric study of the curved duct problem, including aspect ratio of the cross section, the Dean number and the Reynolds number, are currently underway and their results are yet to be summarized. At present, an algebraic turbulence model is used in our 3-D N-S code for high Reynolds number flow.

PLANS FOR THE COMING PERIOD. During the coming three months, we anticipate continuing efforts in all the above areas. Our emphasis will be on completing the acoustic analysis for the indicated vortex problem, and starting to extend to more complicated problems. Work in the unsteady N-S analysis for 2-D airfoil flow problems will continue and the study of axisymmetric flow with swirl should be completed. In

addition, our initial computations of the 3-D parametric study of N-S flow will be summarized and a low level effort will be kept to further validate our 3-D unsteady panel code for marine propeller applications.

Sincerely,

CLM/pm

Charles L. Merkle
Distinguished Alumni Professor
of Mechanical Engineering

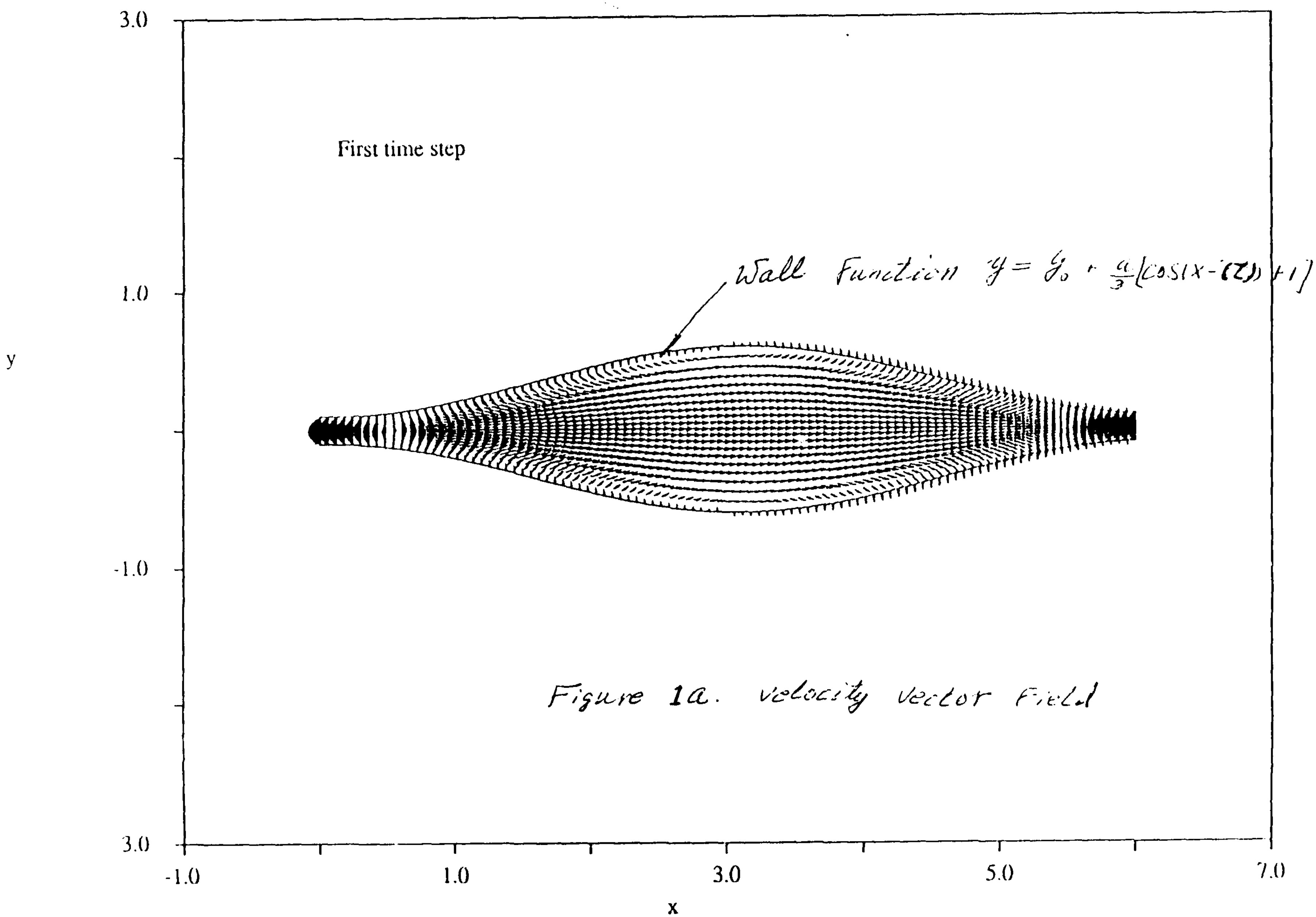

Figure 1a. velocity vector Field

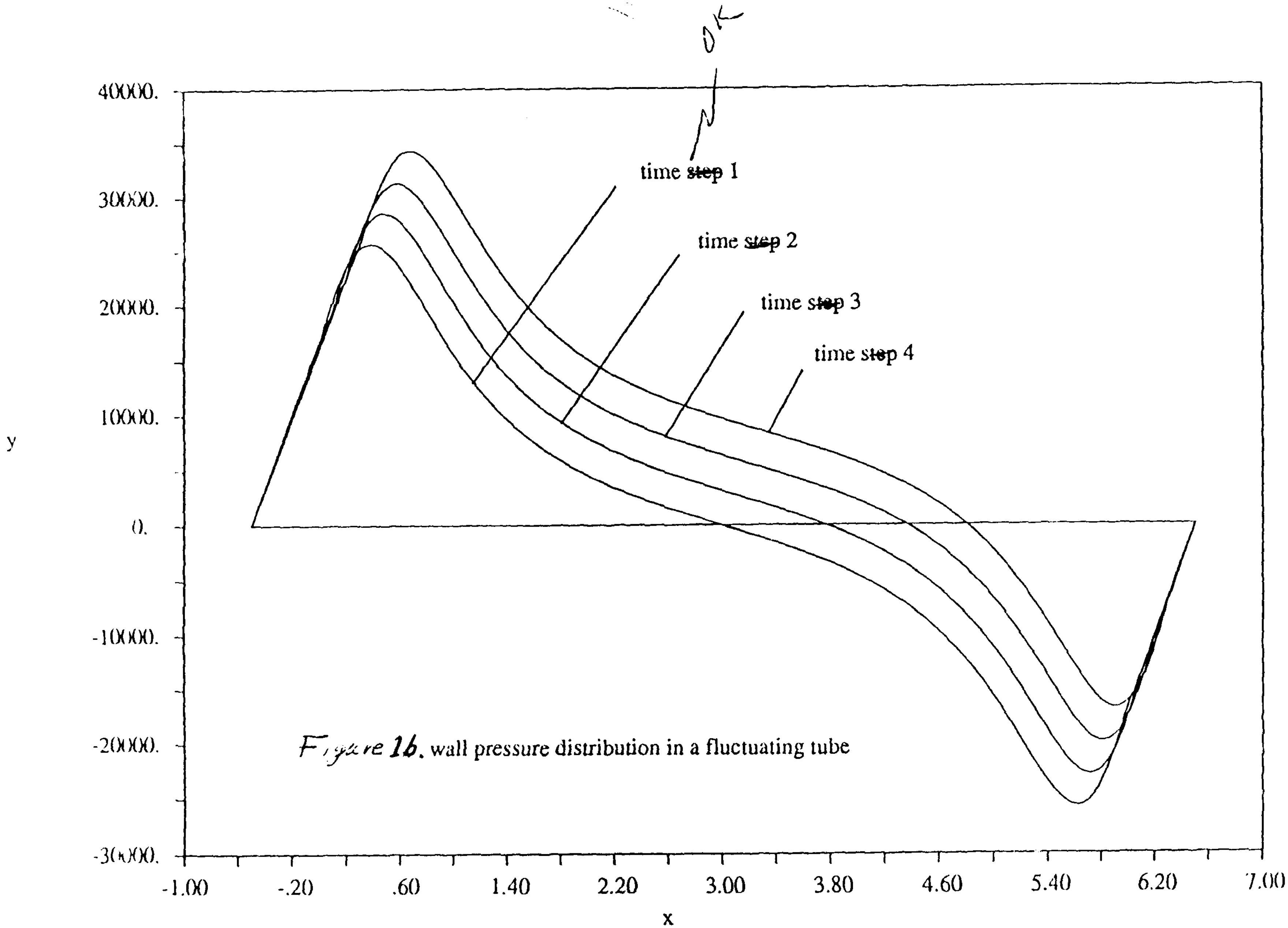

Figure 1b. wall pressure distribution in a fluctuating tube

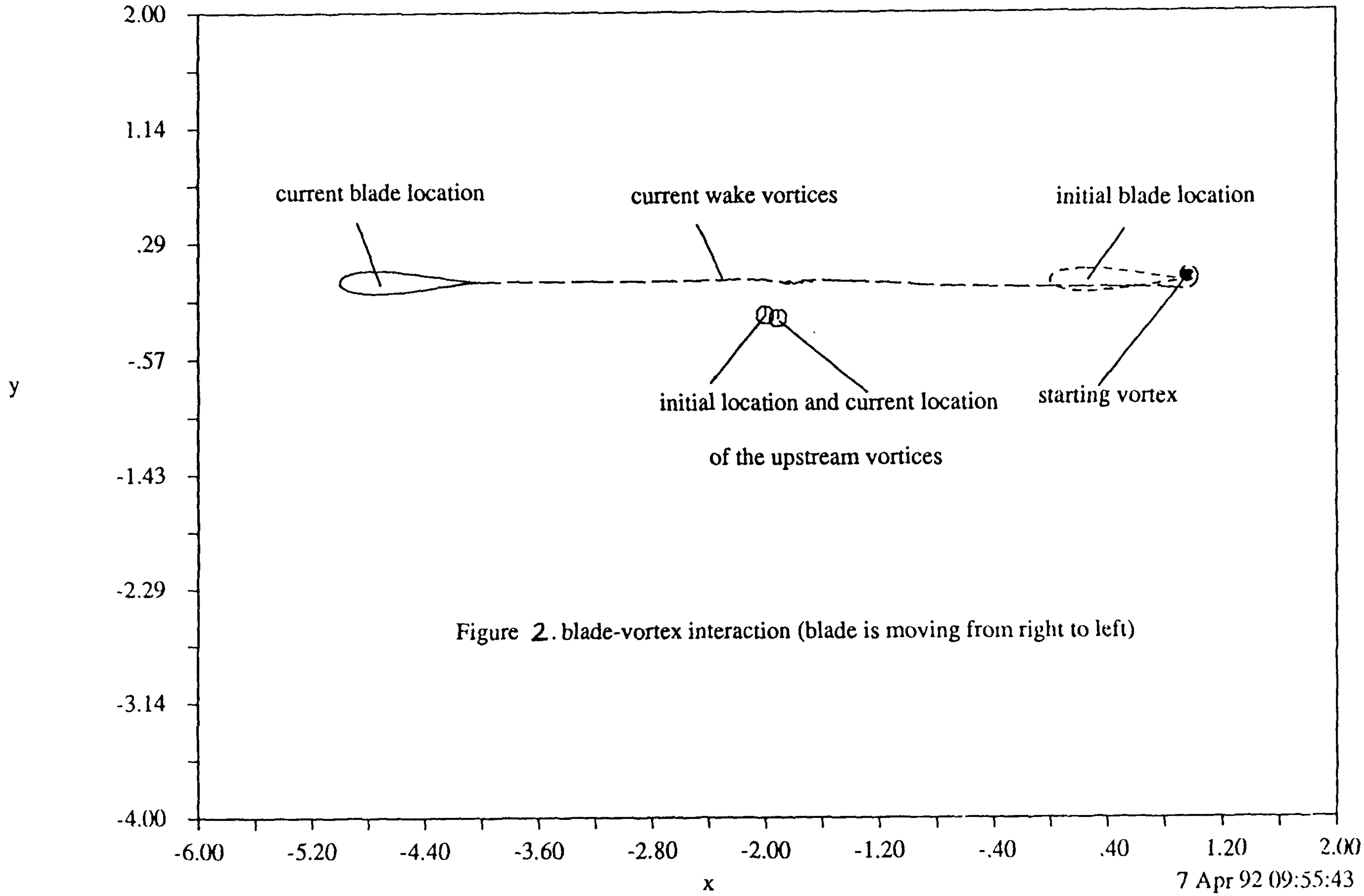

Figure 2. blade-vortex interaction (blade is moving from right to left)

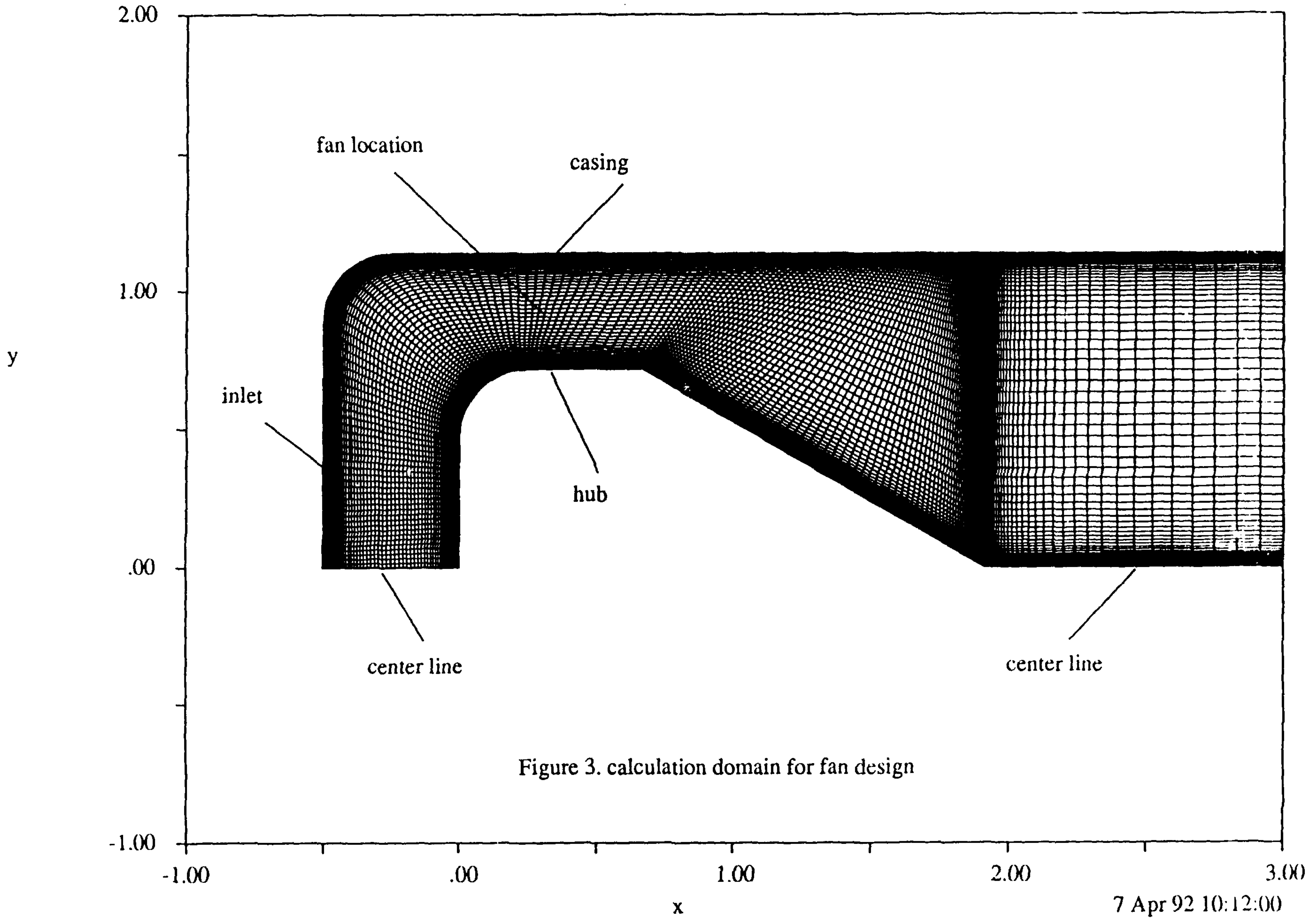

Figure 3. calculation domain for fan design